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# Joint Service Aircrew Mask (JSAM) – Tactical Aircraft (TA) A/P22P-14A Respirator Assembly (V)3: Noise Attenuation and Speech Intelligibility Performance with Double Hearing Protection, HGU-68/P Flight Helmet

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**Interim Report**

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## 14. ABSTRACT

Noise attenuation and speech intelligibility measurements were conducted in accordance with American National Standards Institute (ANSI) S12.6-1997 Methods for Measuring the Real-Ear Attenuation of Hearing Protectors and ANSI S3.2-2009 Method for Measuring the Intelligibility of Speech over Communication Systems on the Joint Service Aircrew Mask–Tactical Aircraft (JSAM-TA) A/P22P-14A Respirator Assembly (V)3 with the HGU-68/P flight helmet in combination with Communications Earplug (CEP) and 3M EAR Classic™ foam earplugs. The objective of these measurements was to determine if the JSAM-TA performance requirements were met when double hearing protection was used. The addition of the JSAM-TA Respirator Assembly (V)3 to both helmet/earplug configurations, HGU-68/P with CEP and HGU-68/P with EAR Classic™, met noise attenuation requirements across all frequencies, ranging from 125 to 8000 hertz (Hz). Additionally, JSAM-TA configurations with the HGU-68/P and both CEP and EAR Classic™ met the speech intelligibility requirement (≥ 80%) for low-noise environments, when using a torso-mounted Intercommunications Unit (ICU), with scores of 85.3% and 83.0%, respectively. In high-noise environments, when hardwired into an aircraft communication system, speech intelligibility requirements with CEP configurations were met with a score of 85.4% at 115 decibels dB. High-noise speech intelligibility requirements were not met for the EAR Classic™ configuration, with a score of 76.7% at 95 dB.

**15. SUBJECT TERMS** JSAM, HGU-68/P, pilot helmet, A/P22P-14A (V)3, speech intelligibility, communications, chemical, biological, protection, hood, CEP, REAT, Communications Ear Plug, 3M, Classic EAR, foam earplugs, noise attenuation, respirator

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The noise environment in the cockpit of military aircraft can be hazardous to hearing and degrade speech communication performance. Hearing protection and communication devices are required for pilots to sustain mission effectiveness and reduce the risk of hearing loss and hearing related disabilities. Flight helmets, when coupled with an oxygen mask, protect the pilot from potentially hazardous noise exposure and provide effective speech communication while providing impact protection and oxygen to the pilot. Chemical/biological/radiological (CBR) protective equipment may also be required to protect aircrew in an actual or potential CBR warfare environment. Wearing CBR protective equipment under a flight helmet could potentially degrade the noise attenuation performance of the helmet and earcups and therefore degrade speech communication capability. The use of double hearing protection, an earplug worn under the earcups in the helmet, in the form of a communication earplug or passive earplug, has been employed to combat this potential problem and to provide additional attenuation and/or communication capability.

Noise attenuation measurements were collected in accordance with the American National Standards Institute (ANSI) S12.6-1997 Methods for Measuring the Real-Ear Attenuation of Hearing Protectors[1] and speech intelligibility measurements were collected in accordance with ANSI S3.2 Method for Measuring the Intelligibility of Speech over Communication Systems[2] for the Joint Service Aircrew Mask-Tactical Aircraft (JSAM-TA) A/P22P-14A Respirator Assembly (V)3 and the HGU-68/P flight helmet with Communications Earplug (CEP) and 3M EAR Classic™ foam earplugs. Measurements were conducted at the Air Force Research Laboratory's (AFRL) bioacoustics facilities at Wright-Patterson Air Force Base (WPAFB) in September-December 2016. The noise attenuation and speech intelligibility results were used to determine if the JSAM-TA Joint Program Office (JPO) requirements were met for ground and in-flight operations. The noise attenuation performance of the JSAM-TA Respirator Assembly (V)3, when worn in combination with the HGU-68/P and CEP or EAR Classic™ foam earplugs, met the JSAM-TA noise attenuation requirements. In low-noise environments, using a torso-mounted Intercommunications Unit (ICU), the speech intelligibility performance of the JSAM-TA Respirator Assembly (V)3 and the HGU-68/P with both CEP and EAR Classic™ foam earplugs met the JSAM-TA requirement for speech intelligibility. In high-noise environments, when connected to an aircraft intercommunication system, the JSAM-TA Respirator Assembly (V)3 and HGU-68/P configuration exceeded the JSAM-TA speech intelligibility requirement when CEP were worn but did not meet the requirement when EAR Classic™ foam earplugs were worn.

# 1.0 INTRODUCTION

The noise environment in the cockpit of military aircraft can be hazardous to hearing and degrade speech communication performance. Hearing protection and communication devices are required for pilots to sustain mission effectiveness and reduce the risk of hearing loss and hearing related disabilities. Flight helmets, when coupled with an oxygen mask, protect the pilot from potentially hazardous noise exposure and provide effective speech communication, while providing impact protection and oxygen to the pilot. CBR protective equipment may also be required to protect aircrew in an actual or potential CBR warfare environment. Wearing CBR protective equipment under a flight helmet could potentially degrade the noise attenuation performance of the helmet and earcups and therefore degrade speech communication capability. The use of double hearing protection, an earplug worn under the earcups in the helmet, in the form of a communication earplug or passive earplug, has been employed to combat this potential problem and to provide additional attenuation and/or communication capability.

The Gentex HGU-68/P Tactical Aircrew helmet (Figure 1) was developed to meet the requirements of a High-G environment for the U.S. Navy and U.S. Marine Corps. The helmet was designed to provide improved comfort, stability, retention, communication, and protection for military aircrew personnel. The HGU-68/P flight helmets used in this study were equipped with OregonAero SoftSeal 3/4" thick earcups, OregonAero ZetaLiner®, single lens safety visor, standard helmet assembly bayonets, and a chin strap. A MBU-23/P oxygen mask with M101/AIC microphone assembly was included in the non-CBR helmet configurations. The OregonAero SoftSeal 3/4" earcups are an approved replacement to the standard issue leather earcups delivered with the HGU-68/P helmet. The OregonAero ZetaLiner® is designed to be worn between the users head and the Energy Absorbing Liner inside of the helmet. The ZetaLiner® is designed to carry perspiration away from the users head, help reduce skin temperature, limit pressure points, and provide a stable fit. The ZetaLiner® is approved for use with the HGU-68/P helmet in five lengths (12, 13, 14, 15, and 16") and four thicknesses (1/4, 3/8, 1/2, and 5/8"). To note, visors were not available during the sound attenuation measurements but were used during the speech intelligibility measurements. Details are discussed in the Discussion section.


**Figure 1. HGU-68/P**

The designated material solution for the JSAM-TA is the A/P22P-14A respirator (currently in use) with incorporated Engineering Change Proposals (ECPs). The ECPs include: four conductor cable pass-through to integrate with CEP, four separate pockets to hold torso assembly and removal of over-vest, 8 inch lower manifold hoses, and anti-stretch retention cords added to the lower manifold hoses. The official nomenclature will be designated at a later time. From this point on, the A/P22P-14A respirator with incorporated ECPs will be referred to as the JSAM-TA Respirator Assembly (V)3. Due to the engineering changes, additional evaluations are required to ensure airworthiness.

The JSAM-TA Respirator Assembly (V)3 (Figure 2) is a chemical, biological, and radiological respirator assembly manufactured by Cam Lock. The respirator assembly consists of a hood and torso assembly. The respirator also includes a rubber hood cowl that incorporates a tear-away component, Advanced Dynamic Oxygen Mask (ADOM), a rubber neck seal, closeable hood outlet valve, and a demist hose. The ADOM oronasal mask includes an articulating visor, inhalation/exhalation valves, M101/AIC microphone assembly, drink facility, inlet hoses, helmet universal bayonets, and a pass-through with plug to attach communication earplugs. The hood assembly is worn under the flight helmet using bayonet receivers to assist in maintaining an oronasal seal. The torso assembly is comprised of various components, including an oxygen hose, demist hose, lower breathing hoses, hose manifolds, pusher fan, pusher fan battery, C2A1 CBR Canister filter for ambient air, C2A1 CBR Canister filter for aircraft oxygen, and ICU. The respirator was provided in small and large sizes with XL, XS, and XXS sizes available through special order, providing the ability to fit a large range of aircrew.

**Figure 2. JSAM-TA Respirator Assembly (V)3 hood (left) and JSAM-TA Respirator Assembly (V)3 hood and torso assembly in combination with the HGU-68/P (right)**

The JSAM-TA Respirator Assembly (V)3 provides individual aircrew head/eye, respiratory, and percutaneous protection against CBR warfare agents, radiological particles, and continuous protection against CBR agent permeation. The JSAM-TA Respirator Assembly (V)3 also provides protection against selected toxic industrial chemicals and toxic industrial materials. When integrated with aircraft-mounted and aircrew-mounted breathing equipment, the system provides combined hypoxia and CBR protection. The respirator can also be integrated with other aircraft subsystems, including but not limited to, Aircrew Life Support Systems, portable aircrew systems, restraint systems, sighting systems, and communications systems.

Communication earplugs, like Communications & Hearing Protection, Inc.'s CEP (left panel in Figure 3), and passive earplugs, like the 3M EAR Classic™ (right panel in Figure 3), have been integrated for use with flight helmets in order to improve the noise attenuation and/or speech intelligibility performance of the combined systems. The CEP configuration used for the HGU-68/P measurements was a passive, vented hearing protection/communication system, with non-custom foam eartips that support mono audio communication via audio cabling part number CEP505-C11-V. Comply™ Canal Tips were used for all CEP configurations and were available in four sizes: slim, short, standard, and large. 3M EAR Classic™ earplugs are passive foam earplugs available in two sizes: Classic and Small.

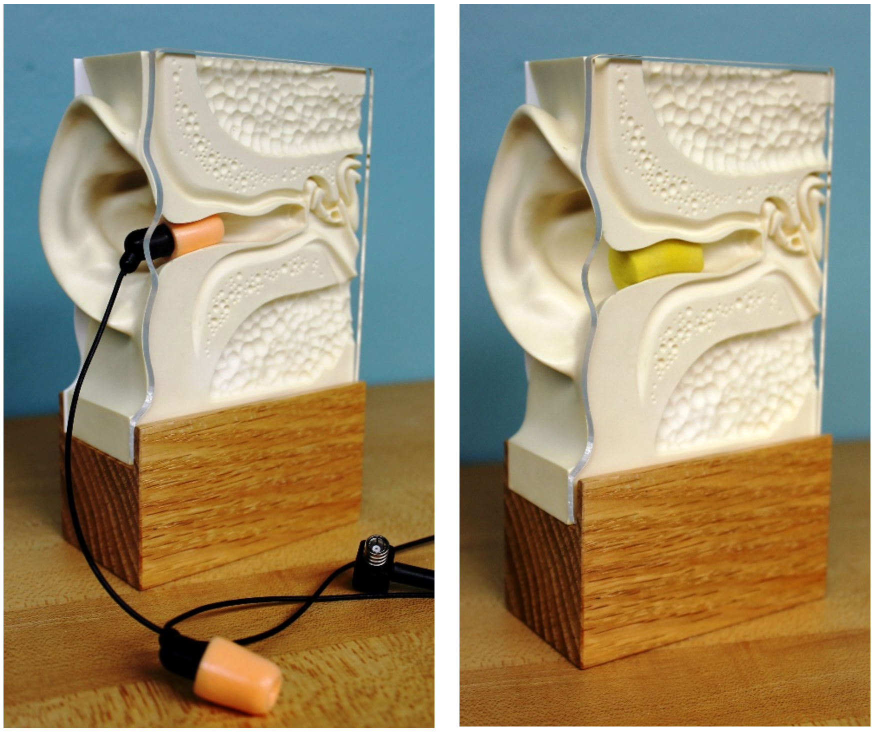

**Figure 3. CEP (left) and 3M EAR Classic™ foam earplugs (right)**

The objective of this study was to measure the noise attenuation and speech intelligibility performance of the JSAM-TA Respirator Assembly (V)3 when donned with the HGU-68/P and CEP or EAR Classic™ earplugs to determine if the CBR respirator met the JSAM-TA JPO performance requirements, as descried in the Purchase Description (PD)[3] as shown below.

> *<u>Hearing Protection / Noise Attenuation</u>*
> *The JSAM-TA, when integrated with existing head-mounted personal/life support equipment, shall result in no more than a 3 decibel, A-weighted (dBA) degradation of the measured one-third octave band hearing protection compared to the non-CBR protection configuration.*
>
> *<u>Speech intelligibility (Low-Noise) - 65 decibel (dB) Background Pink Noise</u>*
> *Ground speech communication should be audible in an environment with 65 dB background pink noise between CBR protected aircrew and unprotected ground personnel at a distance of 1 meter.*
>
> *<u>Speech intelligibility (High-Noise) - 71-115 dB Background Pink Noise</u>*
> *Speech communication should be audible in an environment 71-115 dB Sound Pressure Level (SPL) background pink noise. The speech intelligibility tests shall result in a Modified Rhyme Test (MRT) score as listed below.*
>
> *Speech intelligibility testing shall be measured per ANSI S3.2 for each background pink noise level using a minimum of ten talkers and of ten listeners. The test shall be conducted wearing the JSAM-TA using appropriate communication amplification. Test must include the configurations listed in MRT Configurations table below.*

***MRT Score***

| *Pink Noise Overall Sound Pressure Level (dB SPL)* | *Modified Rhyme Test Score (% Correct)* |
|---|---|
| *75* | *95* |
| *95* | *90* |
| *105* | *85* |
| *115* | *80* |

***MRT Configurations***

| *Helmet* | *JSAM* | *Earplug* | *Pink Noise Level (dB)* |
|---|---|---|---|
| *HGU-84P* | *Listener Only* | *CEP* | *65* |
| *HGU-84P* | *Listener Only* | *EAR Classic™* | *65* |
| *HGU-68P* | *Listener Only* | *CEP* | *65* |
| *HGU-68P* | *Listener Only* | *EAR Classic™* | *65* |
| *HGU-55A/P* | *Listener Only* | *CEP* | *65* |
| *HGU-55A/P* | *Listener Only* | *EAR Classic™* | *65* |
| *HGU-84P* | *Talker & Listener* | *CEP* | *115* |
| *HGU-84P* | *Talker & Listener* | *CEP* | *105* |
| *HGU-84P* | *Talker & Listener* | *EAR Classic™* | *115* |
| *HGU-84P* | *Talker & Listener* | *EAR Classic™* | *105* |
| *HGU-68P* | *Talker & Listener* | *CEP* | *115* |
| *HGU-68P* | *Talker & Listener* | *CEP* | *105* |
| *HGU-68P* | *Talker & Listener* | *EAR Classic™* | *115* |
| *HGU-68P* | *Talker & Listener* | *EAR Classic™* | *105* |
| *HGU-55A/P* | *Talker & Listener* | *CEP* | *115* |
| *HGU-55A/P* | *Talker & Listener* | *CEP* | *105* |
| *HGU-55A/P* | *Talker & Listener* | *EAR Classic™* | *115* |
| *HGU-55A/P* | *Talker & Listener* | *EAR Classic™* | *105* |

# 2.0 METHODS AND RESULTS

The methods and results for both continuous noise attenuation and speech intelligibility measurements are described in the following sections. All measurements were conducted in AFRL facilities at WPAFB, Ohio. Each section includes a description of the subjects, the facilities, and the details of the specific measurement methods and results.

## 2.1 Continuous Noise Attenuation

Continuous noise attenuation performance measurements were collected with human subjects. There were ten male and ten female subjects, ranging in age from 18 to 36 years. All subjects were given a technician- administered screening audiogram via the Hughson-Westlake method, and were required to have hearing thresholds within the normal hearing range: 25 dB Hearing Level (HL) or better from 125 to 8000 hertz (Hz). In addition, anthropometric head measurements were collected by a JSAM-TA Subject Matter Expert (SME) for each subject in order to determine the appropriate size for the HGU-68/P flight helmet and JSAM-TA Respirator Assembly (V)3. Sizing adjustments and all helmet and respirator fittings were conducted by the JSAM-TA SME. The SME was also responsible for familiarizing the test subject with how the helmet and respirator should fit and feel to obtain the maximum amount of hearing protection from the earcups and then visually checking the helmet and respirator prior to the start of each occluded trial. Each subject fit

his/her own earplugs according to the manufacturer's instructions and the sizing and fit were verified by the test administrator. The size of each component of the ensemble employed for each subject is shown in Table 1. If adjustments were made to accommodate for comfort or fit between the helmet/earplug configurations and the helmet/respirator/earplug configurations, the changes are noted in parentheses.

**Table 1. Subject HGU-68/P, JSAM-TA Respirator Assembly (V)3, CEP, and EAR Classic™ sizing matrix**

| Subject ID# | Gender | HGU-68/P Helmet | Helmet Liner (inch) | Earcup Spacers (centered behind both earcups unless noted otherwise) | MBU-23/P Mask | JSAM-TA Respirator Assembly (V)3 | Comply™ Canal Tip | 3M Classic™ |
|---|---|---|---|---|---|---|---|---|
| 15 | M | Medium | 12x1/4 (13x1/4) | 1/4" shim half pad, back | Medium -Narrow | Small | Standard | Classic |
| 1487 | F | Medium | 12x3/8 | 1/4" shim half pad, bottom | Small-Narrow | Small | Standard | Classic |
| 1534 | M | Medium | 12x3/8 (13x3/8) | | Medium -Narrow | Large | Large | Classic |
| 1550 | M | Large | 14x3/8 | 1/2" shim (1/4" shim) | Medium -Narrow | Large | Standard | Classic |
| 1584 | M | Large | 14x3/8 | 1/4" shim | Medium -Narrow | Small | Large | Classic |
| 1602 | F | Medium | 12x3/8 | 1/4" shim | Medium -Narrow | Small | Large | Classic |
| 1622 | F | Medium | 12x3/8 | 1/4" shim half pad, bottom | Small-Narrow | Small | Slim | Small |
| 1625 | M | Large | 14x1/2 | 1/4" shim | Medium -Narrow | Small | Standard | Classic |
| 1628 | M | Medium (Large) | 12x3/8 (13x3/8) | | Medium -Narrow | Large | Large | Classic |
| 1629 | M | Large | 14x3/8 | | Medium -Narrow | Large | Large | Classic |
| 1630 | F | Medium | 12x3/8 (13x1/2) | | Medium -Narrow | Small | Standard | Small |
| 1633 | M | Medium | 12x3/8 | | Medium -Narrow | Large | Standard | Small |
| 1651 | F | Large | 14x3/8 | 1/4" shim | Small-Narrow | Small | Slim | Small |
| 1671 | F | Large | 14x3/8 | 1/4" shim half pad, bottom | Small-Narrow | Small | Standard | Classic |
| 1673 | F | Medium | 12x3/8 (13x3/8) | | Small-Narrow | Small | Slim | Small |
| 1674 | M | Large | 14x3/8 | 1/4" shim | Medium -Narrow | Large | Large | Classic |
| 1683 | F | Medium | 12x3/8 | | Small-Narrow | Small | Standard | Small |
| 1686 | F | Large | 14x3/8 | 1/4" shim | Small-Narrow | Small | Slim | Small |
| 1688 | M | Large | 14x1/2 (14x1/4) | 1/4" shim | Small-Narrow | Small | Standard | Classic |
| 1689 | F | Medium (Large) | 12x3/8 (14x3/8) | | Small-Narrow | Small | Standard | Classic |

The AFRL facility used for this portion of the study was specifically built for the measurement of the sound attenuation properties of passive hearing protection devices. The chamber, its instrumentation, and measurement procedures were in accordance with ANSI S12.6-1997 American National Standard Methods for Measuring the Real Ear Attenuation of Hearing Protectors[1]. The facility is comprised of twelve loud speakers, three mounted in each of the four corners of the room, with a chair positioned in the center of the room for the subject (Figure 4).

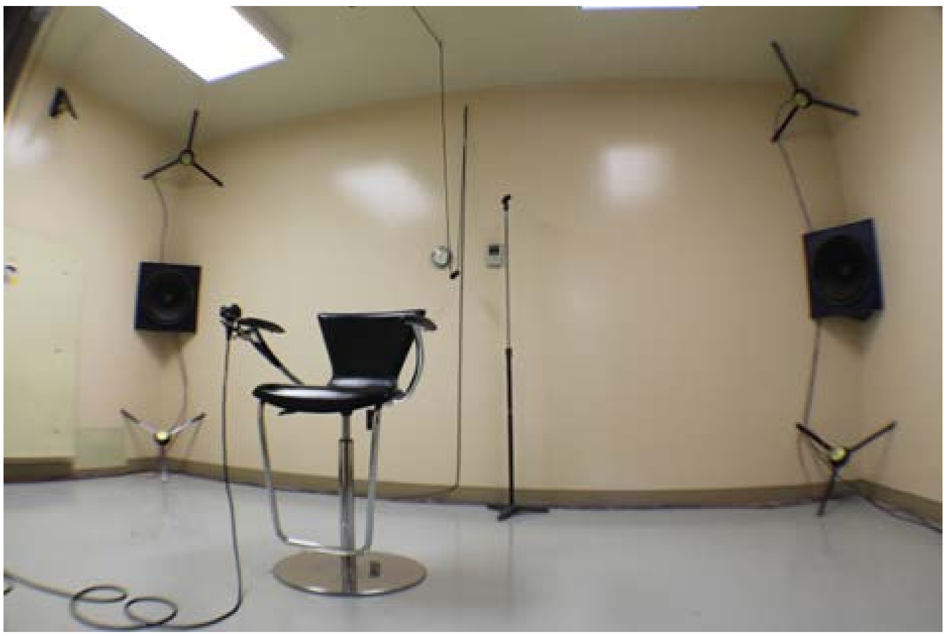

**Figure 4. Facility used for measurement of passive continuous noise attenuation**

Once seated in the room, the subject was tasked to respond to 1/3-octave band stimuli centered at each of the 7 octave band frequencies, ranging from 125 to 8000 Hz. The subject employed a Békésy tracking procedure to complete the measurement and register his/her response via hand-held response wand (Figure 5). When the stimulus was audible, the subject would respond by pressing and holding a button on the response wand. Once the stimulus was inaudible, the subject would release the response button until the stimulus was audible again. This procedure was repeated until a minimum of three comparable thresholds were recorded for each measured octave band.

**Figure 5. Subject completing the REAT measurement in the HGU-68/P, JSAM-TA Respirator Assembly (V)3, and CEP configuration**

ANSI S12.6 requires the measurement of occluded (with helmet/respirator/earplug configuration in place) and unoccluded (without helmet/respirator/earplug configuration in place) hearing thresholds of human subjects. The thresholds for each of the 20 test subjects were measured in two trials for each configuration, paired by unoccluded and occluded ear conditions. The real ear attenuation at threshold (REAT) for each subject, and each configuration, was computed at each octave frequency, 125 to 8000 Hz, by subtracting the unoccluded ear threshold from the occluded ear threshold. The attenuation was then averaged across the two trials for each subject. The mean attenuation performance was calculated across all subjects, at each frequency.

The noise generated by the JSAM-TA Respirator Assembly (V)3 blower exceeded the maximum permissible ambient noise limits outlined in ANSI S12.6-1997 and listed in Table 2[1]. These limits ensure that ambient noise does not impact the attenuation measurement and that each measurement is conducted in a consistent environment. Due to the ambient noise requirement of ANSI S12.6-1997, the JSAM-TA blower was turned off for all attenuation measurements. Also, ANSI S12.6-1997 was used in place of the revised 2016 version to allow for SME fitting for occluded configurations.

**Table 2. Maximum permissible ambient noise for REAT measurements**

| Frequency (Hz) | Octave-band SPL (dB) |
|---|---|
| 125 | 28.0 |
| 250 | 18.5 |
| 500 | 14.5 |
| 1000 | 14.0 |
| 2000 | 8.5 |
| 4000 | 9.0 |
| 8000 | 20.5 |

Mean and standard deviation (SD) noise attenuation data were calculated across subjects at each octave frequency band ranging from 125-8000 Hz. The mean octave frequency band data for the HGU-68/P with CEP configuration were subtracted from the HGU-68/P with CEP and JSAM-TA Respirator Assembly (V)3 configuration to determine compliance with the 3 dB requirement. The same calculations were repeated with the HGU-68/P with EAR Classic™ configuration and the HGU-68/P with EAR Classic™ and JSAM-TA Respirator Assembly (V)3 configuration. The Noise Reduction Rating (NRR) was also calculated for mean minus 1 SD (mean-1SD) and mean minus 2 SD (mean-2SD). Mean-1SD and mean-2SD characterize the amount of attenuation 84% and 98% of the population would expect from a given device or configuration, respectively. Although the NRR was not used directly in any calculation for this study, it provides valuable information to the user by reducing the octave band attenuation data of a device or configuration into a single number rating.

Figure 6 depicts the mean attenuation results at each measured frequency for the four configurations measured in this study. Table 3 contains octave band data, mean and SD, and NRRs. Octave band data from 2000-8000 Hz for all configurations exceeded the bone-conductions limits described in ANSI S12.42-2010 Methods for the Measurement of Insertion Loss of Hearing Protection Devices in Continuous or Impulsive Noise Using Microphone-in-Real-Ear or Acoustic Test Fixture Procedures[4]. Correction factors were applied using the computation method from ANSI S12.42.

When the HGU-68/P was worn with either CEP or EAR Classic™, the addition of the JSAM-TA Respirator Assembly (V)3 met the JSAM-TA JPO requirement. For all frequencies except 2000 Hz, the addition of the respirator increased attenuation by 0.2 to 4.7 dB for the CEP configuration, and by 1.3 to 4.3 dB for the EAR Classic™ configuration, when compared to the helmet and earplug alone. At 2000 Hz, the addition of the respirator resulted in an attenuation loss of 0.5 dB for both the CEP and EAR Classic™ configurations, when compared to the helmet and earplug alone. This 0.5 dB attenuation loss is above the 3 dB degradation limit set by the JPO performance requirement.

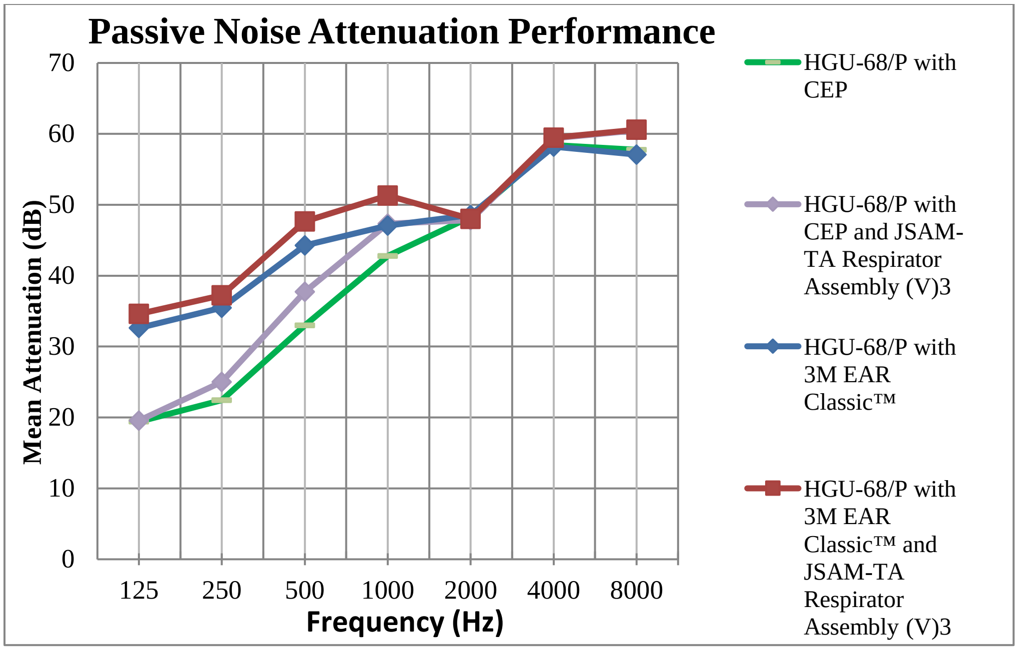


**Figure 6. Mean noise attenuation for HGU-68/P with CEP and HGU-68/P with EAR Classic™, with and without JSAM-TA Respirator Assembly (V)3**

**Table 3. Passive noise attenuation data in dB for HGU-68/P with CEP and HGU-68/P with EAR Classic™, with and without JSAM-TA Respirator Assembly (V)3**

| | | **Frequency (Hz)** | | | | | | | **NRR** | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Configuration** | | **125** | **250** | **500** | **1000** | **2000** | **4000** | **8000** | Mean -1SD | Mean -2SD |
| HGU-68/P with CEP | Mean | 19 | 22 | 33 | 43 | 48 | 58 | 58 | | |
| | SD | 7 | 6 | 6 | 3 | 5 | 4 | 4 | 27 | 21 |
| HGU-68/P with CEP and JSAM-TA Respirator Assembly (V)3 | Mean | 20 | 25 | 38 | 47 | 48 | 59 | 60 | | |
| | SD | 5 | 5 | 3 | 4 | 4 | 4 | 5 | 31 | 26 |
| | Attenuation Gain or (Loss) | **0.2** | **2.6** | **4.7** | **4.6** | **(0.5)** | **0.9** | **2.7** | | |
| HGU-68/P with 3M EAR Classic™ | Mean | 33 | 35 | 44 | 47 | 49 | 58 | 57 | | |
| | SD | 7 | 6 | 6 | 6 | 4 | 4 | 4 | 38 | 32 |
| HGU-68/P with 3M EAR Classic™ and JSAM-TA Respirator Assembly (V)3 | Mean | 35 | 37 | 48 | 51 | 48 | 59 | 61 | | |
| | SD | 6 | 6 | 6 | 5 | 4 | 4 | 5 | 41 | 35 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Attenuation Gain or (Loss) | **2.0** | **1.8** | **3.4** | **4.3** | **(0.5)** | **1.3** | **3.5** | | |

## 2.2 Speech Intelligibility

Speech intelligibility performance measurements were collected with human subjects. Ten subjects (6 male, 4 female) participated in the speech intelligibility measurements. The ten subjects were a subset of the twenty subjects who participated in the noise attenuation measurements. All subjects had hearing threshold levels less than or equal to 25 dB HL from 125 to 8000 Hz. The subjects ranged in age from 19 to 36. The subjects had English as their native language and were trained to participate in the task as both a talker and a listener. All helmet and respirator fittings were conducted by a JSAM-TA SME. Each subject fit his/her own earplugs according to the manufacturer's instructions and the sizing and fit were verified by the test administrator. Generally, the equipment sizing established for the attenuation measurements was carried through to the speech intelligibility portion of the study with only minor adjustments made for subject comfort due to the longer duration of the speech intelligibility measurements. Assigned sizes for each of the subjects are shown in Table 4.

**Table 4. Subject HGU-68/P, JSAM-TA Respirator Assembly (V)3, CEP, and EAR Classic™ sizing matrix for speech intelligibility**

| Subject ID# | Gender | HGU-68/P Helmet | Helmet Liner (inch) | Earcup Spacers (centered behind both earcups unless noted otherwise) | JSAM-TA Respirator Assembly (V)3 | Comply™ Canal Tip | 3M Classic™ |
|---|---|---|---|---|---|---|---|
| 15 | M | Medium | 13x1/4 | 1/4" shim half pad, back | Small | Standard | Classic |
| 1584 | M | Large | 14x3/8 | | Small | Large | Classic |
| 1602 | F | Medium | 12x3/8 | 1/4" shim | Small | Large | Classic |
| 1625 | M | Large | 14x1/2 | 1/4" shim | Small | Standard | Classic |
| 1629 | M | Large | 14x3/8 | | Large | Large | Classic |
| 1633 | M | Medium | 12x3/8 | | Large | Standard | Small |
| 1651 | F | Large | 14x3/8 | 1/4" shim | Small | Slim | Small |
| 1673 | F | Medium | 13x3/8 | | Small | Slim | Small |
| 1674 | M | Large | 14x3/8 | 1/4" shim | Large | Large | Classic |
| 1686 | F | Large | 14x3/8 | | Small | Slim | Small |

The AFRL VOice Communication Research and Evaluation System (VOCRES) facility was used for the speech intelligibility portion of the study. VOCRES was designed to evaluate voice communication effectiveness in operationally-realistic acoustic environments. The facility consists of a programmable, high-power sound system housed in a large reverberant chamber, capable of generating shaped pink noise at levels ranging from 55 to 125 dBA SPL emulating acoustic environments in operational situations. Subject workstations are positioned in the facility (Figure 7), each equipped with a touch-

screen display and communication system capable of replicating end-to-end military communication chains (i.e., intercoms, oxygen systems, headsets, microphones, and helmets). In this way, full communication systems, as well as individual system components, may be evaluated under operational conditions to determine the impact these systems might have on speech intelligibility.

**Figure 7. AFRL's VOCRES facility used to measure speech intelligibility performance**

The MRT was selected for the test material and stimuli were presented by live talker. The MRT consists of 50, six-word lists of monosyllabic English words. The goal was to quantify the ability of trained listeners to correctly identify target words transmitted by a trained talker using the combination of the helmet, respirator, and earplugs. Cueing of target words for the talker and recording of listener responses were both accomplished via a custom MATLAB 7.0 application. A laptop computer with a graphical user interface was utilized for subject response. The talker and listeners had individual computers at their respective work stations.

Measurements were collected in noise for two different configuration modes: low-noise, or ground configuration mode, and high-noise, or flight configuration mode. Measurements were collected for the helmet and respirator with CEP and EAR Classic™ for both configuration modes. The speech intelligibility measurement configuration matrix is listed in Table 5. The talker and listener were in the same noise environment for all configurations.

**Table 5. Speech intelligibility measurement configuration matrix for JSAM-TA Respirator Assembly (V)3 with HGU-68/P and CEP or EAR Classic™**

| Configuration # | Configuration Mode | JSAM-TA Respirator Assembly (V)3 | Earplug Type | | Pink Noise Level (dBA) |
|---|---|---|---|---|---|
| | | | CEP | 3M Classic™ | |
| 1 | Ground | Listener Only | X | | 65 |
| 2 | Ground | Listener Only | | X | 65 |
| 3 | Flight | Talker & Listener | X | | 95 |
| 4 | Flight | Talker & Listener | X | | 105 |
| 5 | Flight | Talker & Listener | X | | 115 |
| 6 | Flight | Talker & Listener | | X | 95 |
| 7 | Flight | Talker & Listener | | X | 105 |
| 8 | Flight | Talker & Listener | | X | 115 |

Low-noise environment measurements were conducted to mimic the operational environment pilots, flight crew, and ground crew may experience on the ground, typically before or after flight. The measurements were conducted with the listener in the JSAM-TA Respirator Assembly (V)3 with the HGU-68/P and either CEP or EAR Classic™ and the talker in the corresponding earplug for passive attenuation only. The subjects were seated at adjacent VOCRES workstations, facing each other, spaced one meter apart, with communication conducted via ICU (Figure 8). The Gentex ICU is designed to enable clear communication from the pilot to rigger/ground crew when a pilot is wearing a JSAM CBR ensemble. The talker transmitted his/her voice over-the-air to the listener's torso mounted ICU. From the ICU, the signal was presented to the listener via either CEP or HGU-68/P earcups, depending on the device configuration. Additionally, the listeners were encouraged to use visual cues, like lip-reading, to assist with the task. Measurements were conducted with the JSAM-TA blower on. All measurements in the low-noise environment were collected at 65 dBA.


**Figure 8. Subjects sitting one meter apart during a low-noise, over-the-air speech intelligibility measurement**

High-noise environment measurements were conducted to mimic operational environments during flight. Subjects were seated at VOCRES workstations, facing forward, with audio hardwired through the facility's intercommunication system, Aircraft Intercom (AIC)-25. The talker's voice was transmitted from the microphone mounted inside the JSAM-TA Respirator Assembly (V)3, though the AIC-25 at the talker's workstation, to the AIC-25 at the listener's workstation, then to the listener via CEP or HGU-68/P earcups, depending on the device configuration. Measurements were conducted with the JSAM-TA blower off. Supplemental breathing air was provided by connecting the JSAM-TA oxygen hose to the facility's supplied air system. Measurements in the high-noise environment were collected at 95 and 115 dBA.

Measurements were conducted in accordance with ANSI S3.2 Method for Measuring the Intelligibility of Speech over Communication Systems[2] with the exception of the number of subjects. Lengthy donning and doffing times and a limited number of helmets and respirators reduced the number of subjects to one talker and one listener at a time.

Ten subjects were divided into five pairs, with each subject in the pair acting as a talker for three MRT lists and as a listener for three MRT lists in a single session, per configuration. During the experimental task, the talker was presented with the stimulus on the computer screen ("You will mark MRT word please"). The talker then communicated the phrase to the listener either over-the-air to the listener's ICU or via AIC-25, depending on configuration. Listeners selected the word heard by using a pen to click on the correct word from a list of six words on the tablet screen. Responses were recorded and an average score was calculated. An example of the MRT format for the talker and listener workstations is provided in Figure 9.

Number 1, you will mark **WENT** please.
Number 2, you will mark **HOLD** please.
Number 3, you will mark **PAT** please.
.
.
.

1.

| | | |
|---|---|---|
| Went | Sent | Bent |
| Dent | Tent | Rent |

2.

| | | |
|---|---|---|
| Sold | Cold | Told |
| Fold | Hold | Gold |

3.

| | | |
|---|---|---|
| Pan | Pad | Pat |
| Path | Pack | Pass |

**Figure 9. Examples of the talker prompt (left) and listener ensemble (right)**

Results were combined for all subjects per configuration. The subjects' scores were adjusted for guessing as described in ANSI S3.2 and the equation below. An overall average was then calculated for all subjects per configuration, Table 6.

$$Score = 2(R - \frac{W}{n-1})$$

Where:

*Score* = Percent Correct (Adjusted For Guessing)
*R* = Number Correct
*W* = Number Incorrect
*n* = 6 (number of choices available to listener)

**Table 6. Speech intelligibility performance of JSAM-TA Respirator Assembly (V)3 with HGU-68/P and CEP or EAR Classic™**

| Configuration # | Configuration Mode | JSAM-TA Respirator Assembly (V)3 | Earplug Type | | Pink Noise Level (dBA) | Score (%) |
|---|---|---|---|---|---|---|
| | | | CEP | 3M Classic™ | | |
| 1 | Ground | Listener Only | x | | 65 | **85.3** |
| 2 | Ground | Listener Only | | x | 65 | **83.0** |
| 5 | Flight | Talker & Listener | X | | 115 | **85.4** |
| 6 | Flight | Talker & Listener | | X | 95 | **76.7** |

In the low-noise environment, speech intelligibility for the JSAM-TA Respirator Assembly (V)3 with the HGU-68/P flight helmet and CEP configuration was 85.3%. Speech intelligibility in the same respirator/helmet configuration with the EAR Classic™ earplug was 83.0%. The JSAM-TA PD did not provide any direct guidance for speech intelligibility performance thresholds in low-noise environments so the threshold set by the Department of Defense (DOD) MIL-STD-1474E was used to determine JSAM-TA JPO compliance: $\geq 80\%$[5]. The speech intelligibility scores for JSAM-TA Respirator Assembly (V)3 with HGU-68/P exceeded the JSAM-TA JPO performance requirements for both earplug configurations in low-noise environments.

For the high-noise environment, the JSAM-TA performance requirement listed four measurement levels: 75, 95, 105, and 115 dBA. If the subjects were able to achieve scores ≥ the threshold set by the requirement for a particular dB level, performance at all lower SPLs was considered acceptable and measurements for that configuration would be complete. A few test trials were completed with each configuration at test levels 95, 105, and 115 dBA to determine the appropriate SPL level to begin the measurement. In the high-noise environment, speech intelligibility performance of the JSAM-TA Respirator Assembly (V)3 with the HGU-68/P flight helmet and CEP was measured at 85.4% at 115 dBA, with no further measurements required. On the opposite end, performance with the same respirator/helmet configuration with EAR Classic™ scored an average of 76.7% at 95 dBA, the lowest measured level. EAR Classic™ failed to meet the threshold requirement and measurements were concluded there. The decision to not proceed with measurements at 75 dBA is detailed in the discussion.

## 3.0 DISCUSSION

The use of CBR protection under a flight helmet has the potential to degrade the noise attenuation performance of the helmet and therefore degrade speech intelligibility performance. Early versions of JSAM performance requirements highlighted the JSAM attenuation requirement as a comparison between the original, helmet only configuration with and without JSAM. Attenuation measurements conducted at AFRL for the JSAM-Strategic Aircraft, JSAM-Rotary Wing, and even an earlier version of the JSAM-TA revealed that this requirement could not be met with single hearing protection[6-8]. In these measurements, the addition of the JSAM respirator created a break in the acoustic seal between the helmet or headset and the subject's head, which resulted in a degradation in attenuation performance (greater than 10 dB at multiple octave frequency bands)[6,8]. The JSAM performance requirements were revised to include the use of double hearing protection to meet JSAM attenuation requirements[3]. Comply™ and 3M both claim users of their foam eartips/earplugs can achieve NRRs greater than 29 dB[9, 10]. This high level of attenuation from the earplugs, coupled with the additional attenuation from the helmet earcups, provided enough overall attenuation to negate the effects of the broken acoustic seal created by the addition of JSAM.

Standard flight helmet configurations generally include a visor assembly to help protect the pilot's eyes from the sun. On more advanced flight helmets systems, the visor may be used for laser eye protection or as a surface to present symbology for information like airspeed, heading, altitude, targeting information, and warnings. The HGU-68/P is issued with a single lens safety visor. These visors were not included with the HGU-68/P flight helmets and components received from the JSAM-TA JPO, and as a result, were not installed during the non-CBR helmet/earplug attenuation measurements. Since the focus of these attenuation measurements was to capture the delta between the CBR and non-CBR helmet/earplug configurations, the visors were not included in the CBR attenuation measurements either. Although the use of a visor could affect the absolute attenuation values of a configuration, it's inclusion or exclusion should not affect the delta between configurations as long as the components of the configuration remained consistent: visor

for both CBR and non-CBR configurations or no visor for both CBR and non-CBR configurations. Due to the extensive amount of data collected without the visors installed and the focus of this portion of the study being the delta between the CBR and non-CBR configurations, it was at the discretion of the lab and JPO to complete the attenuation measurements without the visors installed. The visors were installed for all speech intelligibility measurements.

In legacy systems, passive earplugs (foam) were added to the helmet configuration to reduce the level of noise at the ear; unfortunately, for some users, the added attenuation made it difficult to understand speech. Communication earplugs were developed to improve both speech intelligibility and noise attenuation. These devices ranged from custom molded earpieces to generic fit eartip systems with varying shapes and materials. The benefits of communication earplugs, like CEP, are reflected in the speech intelligibility data collected in this study; all configurations with CEP outscored the respective EAR Classic™ configurations, and the greatest benefit was seen in the highest condition at 115 dBA, with subjects scoring >85%. With EAR Classic™, the subjects were not able to achieve a passing score at 95 dBA. The EAR Classic™ attenuated not only the noise, but also the stimuli from the earcups, even with the volume set at the maximum level. Data from previous studies support that this is not a phenomenon unique to the JSAM-TA with HGU-68/P and EAR Classic™ configuration. Speech intelligibility measurements conducted at AFRL with the F-35 flight helmet and EAR Classic™ yielded results below 20% at 115 dBA, in both the helmet/earplug and helmet/earplug/JSAM configurations[11]. The data suggests that regardless of what helmet or JSAM version is worn, configurations with EAR Classic™ are unlikely to pass speech intelligibility requirements in high-noise environments. This inability to pass appears to be based not on the addition of a JSAM respirator, but the addition of the EAR Classic™ to the configuration. Also, even if the EAR Classic™ configuration was able to pass at 75 dBA, the operational environments where the configuration would be effective would be extremely limited. For example, at cruise, the noise level in the cockpit of a fixed wing military aircraft can range from 99-120 dBA[12]. Accordingly, measurements were not conducted at 75 dBA.

The addition of an earplug to flight helmet configurations is operationally relevant even when a JSAM respirator is not employed. For example, in AFRL conducted attenuation measurements, the NRR (mean-1SD) was 11 dB for the HGU-84/P[7]. If a pilot achieved a similar amount of attenuation from this helmet and was exposed to 105 dB of noise inside the cockpit, he/she would only be permitted to fly for approximately one hour before exceeding DOD noise exposure limits[13]. Additionally, AFRL was unable to conduct speech intelligibility measurements at 115 dB for the HGU-55/P with JSAM-TA (modified A/P22P-14A (V)3) in a study conducted in 2015 due to a similar attenuation level and risk of overexposure to the subjects[8]. This data supports the notion that double hearing protection, not helmet alone, should be the baseline configuration when the HGU-55/P and most other legacy flight helmets, like the HGU-68/P, are worn. Also, based on the speech intelligibility data collected in this and other previously mentioned studies, that earplug should be a communications earplug.

## 4.0 CONCLUSION

Noise attenuation and speech intelligibility measurements were conducted at AFRL in accordance with ANSI 12.6 and ANSI S3.2, respectively, from September-December 2016. Measurements were collected on the JSAM-TA Respirator Assembly (V)3 with the HGU-68/P flight helmet in combination with CEP and EAR Classic™ foam earplugs to determine if JSAM-TA JPO performance requirements were met when double hearing protection was used. The addition of the JSAM-TA Respirator Assembly (V)3 to both helmet/earplug configurations, HGU-68/P with CEP and HGU-68/P with EAR Classic™, met noise attenuation requirements across all frequencies, ranging from 125 to 8000 Hz. Additionally, JSAM-TA Respirator Assembly (V)3 configurations with the HGU-68/P in combination with both CEP and EAR Classic™ met the speech intelligibility requirement (≥ 80%) for low-noise environments, when using a torso mounted ICU, with scores of 85.3% and 83.0%, respectively. In high-noise environments, when hardwired into an aircraft communication system, speech intelligibility requirements with the CEP configuration were met with a score of 85.4% at 115 dBA. Speech intelligibility requirements were not met for the EAR Classic™ configuration, with a score of 76.7% at 95 dBA.

## 5.0 REFERENCES


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## 6.0 LIST OF ACRONYMS

| | |
|---|---|
| (ADOM) | Advanced Dynamic Oxygen Mask |
| (AFRL) | Air Force Research Laboratory |
| (AIC) | Aircraft Intercom |
| (ANSI) | American National Standards Institute |
| (CBR) | Chemical Biological Radiological |
| (CEP) | Communications Earplug |
| (dB) | Decibel |
| (dBA) | A-Weighted Decibel Level |
| (DOD) | Department of Defense |
| (ECPs) | Engineering Change Proposals |
| (HL) | Hearing Level |
| (Hz) | Hertz |
| (ICU) | Intercommunications Unit |
| (JPO) | Joint Program Office |
| (JSAM-TA) | Joint Service Aircrew Mask- Tactical Aircraft |
| (MRT) | Modified Rhyme Task |
| (NRR) | Noise Reduction Rating |
| (PD) | Purchase Description |
| (REAT) | Real Ear Attenuation at Threshold |
| (SD) | Standard Deviation |
| (SME) | Subject Matter Expert |
| (SPL) | Sound Pressure Level |
| (VOCRES) | Voice Communication Research and Evaluation System |
| (WPAFB) | Wright Patterson Air Force Base |